Survey of the Occurrence of Pharmaceuticals and Other Emerging Contaminants in Untreated Source and Finished Drinking Water in Ontario

Ministry of the Environment

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Note of Appreciation:

The Ministry of the Environment (MOE) gratefully acknowledges the participating municipalities, and the owners and operators of the drinking water systems for their cooperation in this special survey.

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Executive Summary

In 2005-2006, the Ontario Ministry of the Environment (MOE) conducted a survey on selected pharmaceuticals and other contaminants of emerging concern to determine their levels and occurrence in untreated source and finished drinking water in Ontario. A secondary objective of the survey was to estimate the overall effectiveness of drinking water systems in Ontario in reducing the levels of pharmaceuticals from source water. In total, 258 samples were collected over a 16 month period from 17 different drinking water systems and were analyzed for 46 compounds, including pharmaceuticals, antibiotics, hormones and bisphenol A (BPA). Of these, 130 samples were source water (125 from river and lake sources and 5 from ground water) and 128 samples were treated drinking water (123 from river and lake sources and 5 from ground water sources). Samples were collected by participating municipalities in the ministry's Drinking Water Surveillance Program (DWSP) and analyzed at the MOE laboratory using liquid chromatography/tandem mass spectrometry (LC/MS-MS) methods. A screening level assessment of drinking water treatment for each of the most frequently detected compounds was carried out by plotting the log-transformed distributions of all source water and all drinking water data.

Of the 46 compounds analyzed, 27 were detected at least once in either untreated source or finished drinking water or both with concentrations measured in the ng/L (or parts per trillion, ppt) range. In total, 23 compounds were detected in source water and 22 were detected in drinking water. The most frequently detected compounds (≥10% detection) in surface water (rivers and lakes) were carbamazepine, gemfibrozil, BPA, ibuprofen, naproxen, lincomycin, sulfamethoxazole, acetaminophen, monensin, benzafibrate, trimethoprim, erythromycin and sulfamethazine. However, monensin and erythromycin measurements did not meet the quality control criteria set for this study's analyses. The most frequently detected compounds (≥10% detection) in finished drinking water were carbamazepine, gemfibrozil, ibuprofen and BPA, with lower measured concentrations than in untreated source water. There were only 5 sampling events that occurred at systems using ground water, and only one compound, ibuprofen, was detected in 1 sample from ground water. Based on comparisons of distributions of source water concentrations to drinking water concentrations drinking water treatment appears to reduce the most frequently detected compounds to some degree. However, these observations were restricted to parent compounds[1] and did not consider metabolites or degradation products.

The survey was limited to environmental presence and did not assess any potential human health effects. However, based on the measured levels of

[1] A parent compound refers to the primary ingredient in a medication (prescription of over the counter) or primary compound that may be used in a product. The parent compound can be degraded or transformed when ingested or adsorbed by an animal and/or may be degraded or transformed once in the environment.

carbamazepine, gemfibrozil ibuprofen and BPA in finished drinking water, an individual would have to drink thousands of glasses of drinking water a day to reach a maximum acceptable daily intake (ADI) for any of these detected compounds in the finished drinking water.

1.0 Introduction

While it has been known for over 20 years that pharmaceuticals can enter the environment, it has only been in the last 10 years that we have begun to identify and quantify their presence in sewage treatment plant (STP) effluents, receiving waters, ground water, in agricultural settings (tile drains and run-off) and drinking water. Our understanding of the environmental presence of pharmaceuticals is improving with the development of improved analytical methods. The science needed to assess the potential impact of these compounds on the environment and human health is still emerging.

The public has expressed concern regarding the implications of these trace level contaminants in finished drinking water and the issue has been highlighted in several Ontario and Canadian reports: Justice O'Connor's recommendations in part II of the Walkerton Report (2002) that "water providers must keep up with scientific research on endocrine disrupting substances and disseminate the information"; a CTV National survey on pharmaceuticals in finished drinking water (2003); and, more recently a report released by the National Water Research Institute (Servos et al., 2007). To date, more than 30 different pharmaceuticals or other contaminants of emerging concern have been detected in finished drinking waters world-wide and reported in peer-reviewed journals. The detection of these compounds in finished drinking water is attributed to their presence in the untreated source water and the inability of the treatment process at the drinking water system to completely remove them.

The Ontario Ministry of the Environment (MOE), in collaboration with a subset of municipalities that participate in the Ministry's Drinking Water Surveillance Program (DWSP), initiated a province-wide survey to determine the levels and occurrence of pharmaceuticals and other emerging contaminants in untreated source and finished drinking water in Ontario. A secondary objective of the study was to determine whether existing treatment processes at Ontario drinking water treatment plants are effective at reducing the levels of pharmaceuticals and other emerging contaminants in finished drinking water. This report provides a summary of the survey.

2.0 Background

Pharmaceuticals are known to have specific biological effects in humans at their "therapeutic" level. A therapeutic level is defined as the dose range within which a prescribed effect is observed in most individuals. Pharmaceuticals detected in the environment and in finished drinking water are found well below these levels; in fact, the range of detection/quantitation is between hundreds to thousands of times lower than the human "therapeutic" level (Christensen, 1998; Schulman et al., 2002; Schwab et al., 2005 and Whillhite et al., 2008).

Evaluation of the risk posed to humans by long-term consumption of minute quantities of pharmaceutical compounds in finished drinking water represents an area where the science is still emerging. Some concerns have been raised regarding exposure of highly vulnerable groups, such as sensitive individuals with specific drug allergies, the elderly and children, being continually exposed to trace amounts of these substances through finished drinking water. However, research to date on single compounds has not shown evidence of effects and several reports have indicated that the low levels of pharmaceuticals in drinking water do not pose a risk to human health (Christensen, 1998; Schulman et al., 2002; Webb et al., 2003; Schwab et al., 2005 and Cunningham et al., 2009).

At this time, there are no Canadian Drinking Water Quality Guidelines or Ontario Drinking Water Quality Standards for pharmaceuticals, nor has any jurisdiction established maximum acceptable concentrations based on health effects. However, some jurisdictions and research institutions have addressed this issue. For example, the Netherlands and the Pharmaceutical Research and Manufacturers of America (P*h*RMA) have publicly stated that there are no human health concerns with regard to trace levels of pharmaceuticals in finished drinking water. Australia, to support a multi-barrier approach for the sustainable recycling of waters, has set (for recycled drinking water) non-regulatory guidelines for human and veterinary pharmaceuticals in their "Guidelines for Water Recycling: Managing Health and Environmental Risks (phase 2): Augmentation of Drinking water Supplies" (Australian Environment Protection and Heritage Council).

3.0 Description of the Survey

3.1 Drinking Water Surveillance Program

The Ministry of the Environment's Drinking Water Surveillance Program (DWSP) facilitated the survey. The DWSP is a science-based program administered by the ministry's Environmental Sciences and Standards Division. It has been operational since 1986 primarily through a valued partnership arrangement with municipalities. Currently, 113 municipal drinking water systems participate in the DWSP on a voluntary basis.

3.2 Drinking Water Systems

A cross section of drinking water systems was selected for the survey to reflect a range of source water types, treatment processes and proximity to municipal sewage treatment plants and agricultural activities.

As shown in Table 1, a total of seventeen (17) drinking water systems (DWS) in Ontario participated in the survey. Eight (8) used river water as the source (1-8), seven (7) systems used lake water as the source (inland and Great Lakes: 9-15), and two (2) used ground water as the source (16, 17). All plants were operating under normal conditions at the time of sampling.

Table 1: Description of Treatment Process and Source Water Type at Surveyed Drinking Water Systems (DWS)

DWS	Source	Treatment
1	River	Disinfection with Chlorination, Powdered Activated Carbon (PAC), Filtration using Anthracite Coal and Sand, Fluoridation
2	River	Disinfection with Chlorination (Sodium Hypochlorite), Filtration using Granulated Activated Carbon (GAC) and Sand , Fluoridation
3	River	Disinfection with Chlorination, Filtration using GAC and Sand, Fluoridation
4	River	Disinfection with Chlorination (Sodium Hypochlorite), Filtration using GAC, Fluoridation
5	River	Disinfection with Chlorination (Chlorine and Chlorine Dioxide, Sodium Chlorite*), Filtration using Anthracite Coal and Sand, Fluoridation
6	River	Disinfection with Chlorination, Filtration using GAC, disinfection with Ultraviolet (UV) Irradiation
7	River	Disinfection with Chlorination (Chlorine and Chloramination), Filtration, Pre UV Irradiation
8	River	Disinfection with Chlorination, Filtration using GAC and Sand, Pre UV Irradiation, Fluoridation Chlorine, Pre UV and Fluoridation
9	Lake	Disinfection with Chlorination (Sodium Hypochlorite), Filtration using Anthracite Coal and Sand
10	Lake	Disinfection with Chlorination (Chlorine and Sodium Hypochlorite), Filtration using Anthracite Coal, PAC*, Sand and Gravel, Fluoridation
11	Lake	Disinfection with Chlorination, Membrane Filtration
12	Lake	Disinfection with Chlorination, Filtration using GAC, Anthracite Coal and sand, Fluoridation
13	Lake	Disinfection with Chlorination, Filtration using Dual Media Anthracite/Sand, Fluoridation
14	Lake	Disinfection with Chlorination, Filtration using PAC*, Anthracite Coal, Sand, Fluoridation
15	Mixed	Disinfection with Chlorination, Filtration using Anthracite Coal, sand and Mixed Media Sand
16	Ground Water	Disinfection with Chlorination (Sodium Hypochlorite), Filtration using Anthracite Coal and Manganese Green sand
17	Ground Water	Disinfection with Chlorination

* used for taste and odour control

3.3 Sampling Program

DWSP staff prepared the sampling schedule for each participating system. Sample shuttles containing bottles, submission forms and detailed sampling instructions outlining sampling methodology, sample preservation requirements and quality assurance and quality control (QA/QC) measures were sent to system operators in time for prescribed sampling events. Samples were collected according to Laboratory Services Branch (LaSB) prescribed method E3454 (MOE, 2006). The operators collected the samples and returned them to the MOE laboratory in Toronto for analysis. In total, 258 samples were collected over a 16 month period from September 2005 to December 2006. Of these samples, 130 were untreated source water taken at the drinking water system and 128 were finished drinking water. As shown in Table 2, the number of sampling events ranged between a minimum of one sampling event to a maximum of 15 depending on the system. The reason for such variability is that the survey was voluntary and drinking water systems were able to withdraw from the survey at any time, in which case, new systems could then be added.

It is important to note that the retention time (the amount of time between water entering and leaving the drinking water system) was not taken into account at the time of sampling, as it was assumed that the source water characteristics would not vary significantly.

Table 2: Number of Sampling Events at each Drinking Water System

Drinking Water System	Number of Sampling Events
1	9
2	15
3	10
4	9
5	10
6	12
7	3
8	5
9	5
10	5
11	5
12	5
13	5
14	10
15	15
16	1
17	4

3.4 Compounds Analyzed

Samples were analyzed for a total of 46 compounds. The compounds of interest included antibiotics, hormones, pharmaceuticals, and other emerging contaminants (Table 3). The analyses were limited to only parent compounds and did not include metabolites or degradation products. Appendix A provides additional details regarding the parent compounds included in the survey.

Table 3: Groups and Numbers of Compounds Analyzed

Group	Number of Compounds Analyzed	OVERVIEW
Antibiotics	25	Antibiotics are medicines commonly used to treat or prevent bacterial infections in humans, pets and agricultural livestock. They find their way into source waters via sewage treatment plant discharges or by runoff from agricultural activities such as manure spreading, land application of biosolids or feedlot operations.
Hormones	9	Hormones are natural or synthetic compounds that are used for cell regulation in the endocrine and reproductive systems in humans and animals.
Pharmaceuticals	11	The compounds in this category are active pharmaceutical ingredients (API) in many medications prescribed to soothe headaches and other aches and pains, reduce cholesterol or treat depression. Many are available as common over the counter medications at drugstores.
Emerging Contaminants	1	Bisphenol A (BPA) is a chemical used in polycarbonate plastics and is a suspected endocrine disrupting compound.

3.5 Sample Analysis and Statistical Reporting of Data

Laboratory Services Branch (LaSB) method E3454 was used for analyzing the samples in this survey. Method E3454 has been accredited by the Canadian

Association for Environmental Analytical Laboratories (CAEAL) since 2004[2].

Method E3454 uses solid phase extraction (SPE) to extract the target compounds (analytes) from a sample and analyzes them by using liquid chromatography / isotope dilution tandem mass spectrometry (IDMS) technology (Hao et al., 2008).

To evaluate the accuracy of Method E3454 in measuring the low levels of these compounds, the laboratory used standard solutions with a maximum acceptable range of recovery set at 100 ± 20%. Recovery is a comparison of the concentrations of a compound in an unknown sample to the same compound in a standard chemical solution. Recovery is usually presented as a percentage and is used to evaluate or correct the measured concentration of a compound in a sample. All compounds were analyzed using two kinds of standards: standard chemical solutions (of known chemical composition) or radioisotope labelled standards (chemical isotopes that can be readily distinguished by the mass spectrometer to verify the concentrations of a specific compound).

A list of all compounds and their associated standards is provided in Appendix A. For the compounds that had corresponding radioisotope labelled standards, all concentrations were corrected according to the measured radioisotope standard recovery. For compounds that had standard chemical solutions only, the concentrations were not corrected since this measurement is less accurate.

Reporting of low / trace concentrations followed the standard practice of the ministry laboratory for reporting drinking water results. For those results below which the method is not able to detect a measurable concentration, the result is flagged as less than or equal to the detection limit of the method ("<=W"), indicating that the compound is not detected at the value of the "W". Just above this "W" value, there is a range in which the method is able to detect trace levels of a compound without a high level of certainty in the concentration measured. These results are assigned a qualifier of "<T". In this study, the "T" threshold concentration was established at 10 times the "W" value. Depending on the rounding process, "T" is approximately the value of the 2 times the method detection limit (MDL) calculated according to the United States Environmental Protection Agency's protocol.

Environmental surveillance datasets with a very high proportion of non-detects (nd), represent a challenge in terms of data analysis. In this report, for

[2] Method E3454 was not a licensed method at the time when sampling and analysis took place The requirement of using an inspected and licensed analytical method for drinking water analysis was fulfilled by using section 5 (2) of Ontario Regulation 248/03 with a written proposal that outlined the objective, scope and time-frame of this survey according to the Ministry of the Environment (MOE), Laboratory Services Branch Procedures for Processing and Reporting Drinking Water Samples, version 2.0 (Operating Procedure #39 (LSBSOP.039 as updated, 2008).

compounds deemed to be at levels "<=W" or non-detect, a statistical approach was applied in order to obtain reliable estimates of the population (all samples). The statistical approach that was used incorporated all the non-detect samples by weighting their occurrence to the number of detections (Minitab Statistical software with special routines, Helsel, 2009). This approach, using "left censored data analysis", may result in values for some of the summary statistics (median or 95th percentile values) being less than the "W" value (instrument detection limit) for a compound, especially when there is a large proportion of non-detected results for that compound (Helsel, 2005, 2009). In some cases median values cannot be reliably calculated if the percent detected are below about 20%.

Because paired source water and drinking water samples were not compared, and due to the limited number of samples collected, this study did not attempt to evaluate the effectiveness of an individual treatment system in reducing the levels of pharmaceuticals or other emerging contaminants from source water. Instead, the data from all plants were pooled together regardless of treatment, to estimate the overall ability of treatment systems in Ontario to reduce the levels of individual compounds from source water to the finished drinking water. For each compound, the distribution of all the data from the source water and the drinking water were plotted and compared.

4.0 Results

This chapter provides a summary of the levels and occurrence of pharmaceuticals and emerging contaminants in untreated source and finished drinking water.

4.1 Analytical Quality Assurance / Quality Control (QA/QC)

All 15 compounds measured by radiolabeled isotopes were within the acceptable recovery range of 100 ± 20%. Of the samples validated by chemical solutions, the most frequently detected compounds in untreated source and finished drinking water (detected ≥ 10% of the time) were within the recovery range of approximately 100 ± 20% except for monensin sodium (190% ± 49%). Less frequently detected compounds (detected less than 10% of the time) that had recoveries outside this range included erythromycin (137%) and tylosin (177%). This range of recovery is a well documented phenomenon associated with the analysis of these compounds (Pfeifer et al., 2002, Hernando et al., 2004 and Hao et al., 2007). Appendix A lists the percent recoveries for all individual compounds with both chemical and radioisotope standards.

For compounds without standards, the accuracy of the measurement could not be verified. For this reason, measurements for two antibiotic compounds, penicillin G and virginiamycin were excluded from this report.

4.2 Detection of Pharmaceuticals and Other Emerging Contaminants in Untreated Source and Finished Drinking Water

Of the 46 reportable compounds, 27 compounds were detected (i.e. results above “W”) on at least one occasion in either untreated source water, finished drinking water or both (Appendix B).

As shown in Table 4, 23 compounds were detected in source water (including ground water) and 22 compounds were detected in drinking water. Fourteen (14) compounds, or just over half of the measured antibiotic compounds, were detected at least once in untreated source water and 12 were detected on at least one occasion in finished drinking water. Only 1 hormone was detected in finished drinking water. Of the 11 pharmaceuticals, 7 were detected on at least one occasion in untreated source water and 8 were detected in finished drinking water. BPA was detected in both untreated source and finished drinking water.

Table 4: Distribution of Types of Compounds Analyzed and Detected in Either Untreated Source* or Finished Drinking Water

Group	Number of Compounds Analyzed	Number of Compounds Detected in Untreated Source Water	Number of Compounds Detected in Finished Drinking Water
Antibiotics	25	14	12
Hormones	9	1	1
Pharmaceuticals	11	7	8
BPA	1	1	1
Total	**46**	**23**	**22**

*includes ground water sources

There are a number of factors that may influence whether a particular compound is detected in either untreated source or finished drinking water. One consideration is the consumption or usage of a particular compound and the availability of the compound in question. For example, compounds that are heavily used and readily available (e.g. those found in consumer products or over the counter medications) have a greater potential to migrate into the natural environment. How the compound is used by the host, whether human or animal, is also a contributing factor in the availability of the compound to the natural environment. Some antibiotics, synthetic hormones or pharmaceuticals are well metabolized whereas others are excreted unmetabolized (conjugated / bound or as a metabolite of the parent or original compound). Some of the compounds enter the natural environment in runoff from agricultural areas or are discharged by sewage treatment plants to surface waters. Once in the natural environment compounds may undergo photodegradation or other degradation/transformation processes so the proximity of sources and resultant travel times to drinking water intakes is also a contributing factor in what might be detected in untreated source water at water treatment plants. The effectiveness of a drinking water system's treatment process to reduce the levels of pharmaceuticals or other emerging contaminants also plays a role in determining which compounds and what concentrations may end up in the finished drinking water.

Results from the two drinking water systems using ground water were separated from those that used rivers or lakes as their source waters. There were only 5 sampling events that occurred at the ground water systems, and only one compound, ibuprofen, was detected in 1 sample from these systems. For these reasons, the remainder of the document and discussion will focus on those systems that used either river or lakes as their untreated source water.

As shown in Table 5, the most frequently detected compounds (≥ 10% detection) in the untreated source waters (river and lakes) in this survey were: carbamazepine (50%), gemfibrozil (33%), BPA (22%), ibuprofen (21%) and

naproxen (21%), followed by lincomycin (19%), sulfamethoxazole (18%), acetaminophen (11%), monensin (11%), benzafibrate (10%) trimethoprim (10%), erythromycin and sulfamethazine (10%) (Table 5). However, the average percent recovery for monensin (190% ± 49%) and erythromycin (137% ± 46%) was outside the acceptable recovery range (100 ± 20%) and, therefore, these compounds were excluded from further data analysis.

Some compounds were detected frequently (i.e., at least 10%) in untreated source water but infrequently (less than 10%) in drinking water. These included lincomycin, sulfamethoxazole, acetaminophen, benzafibrate and trimethoprim all with a percent detection of 2% or less. Additionally, naproxen and sulfamethazine were not detected at all in drinking water in spite of a 21% and 10% detection, respectively, in source water.

The most frequently detected compounds in finished drinking water (≥ 10% detection) were carbamazepine (25%), ibuprofen (15%), gemfibrozil (15%) and BPA (12%) (Table 5). Four (4) compounds (sulfachloropyridazine, clofibric acid, diclofenac and equilin) were detected in the finished drinking water but were not detected at all in the untreated source water. These observations could be due to the fact that the sample collection did not account for retention time and/or that the levels detected were at or near the limit of detection.

Table 5: Compounds Detected* in Untreated Source and Finished Drinking Water

(*Based on 125 samples per compound in untreated source (river and lake) and 123 samples per compound for finished drinking water (river and lake sources))

Compound	Group	Sample type	Number of Detections	Percent Detection (%)	Number of sites n=17
Compounds Detected in Untreated Source Water and Finished Drinking Water					
Carbamazepine	Pharmaceutical	Untreated	63	50	10
		Finished	31	25	8
Gemfibrozil	Pharmaceutical	Untreated	41	33	7
		Finished	18	15	6
Bisphenol A	Emerging Contaminant	Untreated	27	22	11
		Finished	15	12	11
Ibuprofen	Pharmaceutical	Untreated	26	21	9
		Finished	19	15	9
Lincomycin	Antibiotic	Untreated	24	19	6
		Finished	3	2	3
Sulfamethoxazole	Antibiotic	Untreated	23	18	8
		Finished	1	1	1
Acetaminophen	Pharmaceutical	Untreated	14	11	8
		Finished	1	1	1
Benzafibrate	Pharmaceutical	Untreated	13	10	2
		Finished	2	2	1

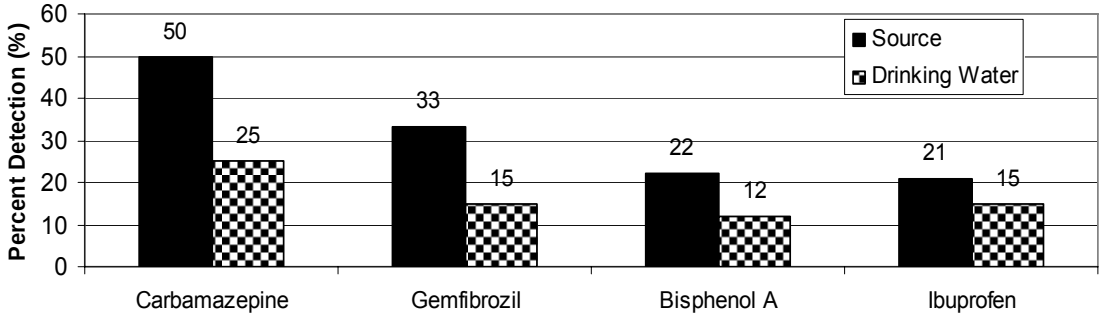
Compound	Group	Sample type	Number of Detections	Percent Detection (%)	Number of sites n=17
Trimethoprim	Antibiotic	Untreated	13	10	3
		Finished	1	1	1
Erythromycin*	Antibiotic	Untreated	12	10	4
		Finished	4	3	4
Ketoprofen	Pharmaceutical	Untreated	11	9	3
		Finished	1	1	1
Tylosin	Antibiotic	Untreated	5	4	5
		Finished	8	6	4
Monensin Sodium*	Antibiotic	Untreated	14	11	7
		Finished	9	7	4
Enrofloxacin	Antibiotic	Untreated	3	2	3
		Finished	4	3	4
Roxithromycin	Antibiotic	Untreated	3	2	3
		Finished	3	2	3
Tetracycline	Antibiotic	Untreated	3	2	3
		Finished	5	4	5
Norfloxacin	Antibiotic	Untreated	2	2	2
		Finished	1	1	1
Meclocyclin	Antibiotic	Untreated	1	1	1
		Finished	1	1	1
Compounds Only Detected in Untreated Source Water					
Naproxen	Pharmaceutical	Untreated	26	21	5
Sulfamethazine	Antibiotic	Untreated	12	10	4
Norethisterone	Antibiotic	Untreated	1	1	1
Oxytetracycline	Antibiotic	Untreated	1	1	1
Sulfathiazole	Antibiotic	Untreated	1	1	1
Compounds Only Detected in Finished Drinking Water					
Sulfachloropyridazine	Antibiotic	Finished	2	2	2
Clofibric acid	Pharmaceutical	Finished	1	1	1
Diclofenac	Pharmaceutical	Finished	1	1	1
Equilin	Hormone	Finished	1	1	1

* chemical analysis did not meet QA/QC standards for recovery. See Appendix A.

4.2.1 General Description of the Most Frequently Detected Compounds

This section provides a detailed description of the classification, type and use of the most frequently detected compounds (≥ 10%) in untreated source (river and lake) and finished drinking waters (Figure 1).

Figure 1: Most Frequently Detected Compounds (%) in Untreated Source and Finished Drinking Waters in Ontario



Carbamazepine is a prescription drug that is used for the treatment of epilepsy, as well as for various psychotherapy applications. In Canada, approximately 28 tons of carbamazepine were sold as prescriptions in 2001 (IMS Heath Canada, 6755 Mississauga Rd., Mississauga, ON, L5N 7Y2, Canada). Katzung, (1998) reported that carbamazepine is completely metabolized in humans. In 2006, Hua et al., estimated that the parent compound carbamazepine and its metabolites are released into the environment from sewage treatment plants (STPs). Many studies have been completed to date on the potential photodegradation (ability of UV / sunlight to break down the compound) of carbamazepine in surface waters. The half-life, or the time required for half of the amount of the compound present to breakdown, is about 115 hours or 4.5 days (Lam and Mabury, 2005). Carbamazepine appears to be more persistent than other pharmaceuticals in the aquatic environment.

Gemfibrozil is a prescription drug that is used for the treatment of cholesterol and is a lipid regulating agent. Approximately 70% of the ingested drug is eliminated / excreted unchanged by humans (Katzung, 1998). The remaining drug is metabolized and excreted in a conjugated (bound or unavailable) form or as a metabolite. Gemfibrozil has been shown to undergo photodegradation in river water, with an estimated half-life of 15 hours (Lin and Reinhard, 2005).

Bisphenol A (BPA) is a chemical intermediate primarily used to make polycarbonate plastic and epoxy resins. It is used in medical and health-care products such as syringes and pill containers, enclosures for consumer electronics and in the home and office, safety equipment, food packaging and in a variety of materials used in the automotive industry. In 2006, BPA was not manufactured in Canada at quantities greater than the reporting threshold of 100 Kg. However, approximately half a million kilograms of BPA were imported into Canada in a product, in a mixture, or in a manufactured item (Health Canada and Environment Canada, 2009). BPA is also a suspected endocrine disrupting agent, in that it has been shown in some scientific studies to bind and interfere with the estrogen receptor. BPA has been found in municipal and industrial wastewaters, sludge, and biosolids (Lee et al., 2002, 2004). BPA has been found in surface waters, sediment, and ground water in many locations in North

America indicating that it is widely distributed throughout the environment.

Studies have been completed to date on the potential photodegradation of BPA in water. The half-life of BPA is about 2.4 – 4 days.

Ibuprofen is the main ingredient in many over-the-counter analgesic drugs such as Advil and used to treat fever, inflammation and arthritis. It belongs to a group of drugs referred to as Non-Steroidal Anti-Inflammatory Drugs (NSAIDs). Ibuprofen is extensively metabolized in the liver of humans and less than 1% of the parent compound is excreted unchanged (Katzung, 1998). The remaining drug is metabolized and excreted in a conjugated (bound or unavailable) form or as a metabolite. Ibuprofen has been shown to undergo photodegradation in river water, with an estimated half-life of 15 hours (Lin and Reinhard, 2005).

4.2.2 Levels, Occurrence and Description of the Most Frequently Detected Compounds in Untreated Source Water

This section provides a detailed description of the concentrations (median, 95th percentile and maximum values) of the most frequently detected compounds in untreated source water (≥ 10%, Table 6) and how these levels compare to previous reports and other jurisdictions. Where other studies reported median and mean concentrations based on detected samples only, results of this study are calculated based on both detected and censored data approaches to allow for comparisons.

Table 6: Number of Detections and Concentrations for the Most Frequently Detected Compounds in Untreated Source Water (rivers and lake sources) in Ontario (n= 125)

Compound	Number of Detections	Detection Percentage (%)	Detection Limit (ng/L)	Median (ng/L)	95th Percentile (ng/L)	Maximum (ng/L)
Carbamazepine	63	50	1	3	152	749
Gemfibrozil	41	33	1	0.7	6	9
Bisphenol A (BPA)	27	22	2	2.1	44	87
Ibuprofen	26	21	0.5	0.98	24	79
Naproxen	26	21	2	1.0	58	199
Lincomycin	24	19	0.5	0.12	15	143
Sulfamethoxazole	23	18	2	0.17	28	284
Acetaminophen	14	11	2	0.1	95	298
Benzafibrate	13	10	0.5	0.2	2	3.6
Trimethoprim	13	10	1	0.4	11	25
Sulfamethazine	12	10	1	0.055	4.5	34

Carbamazepine was detected in 50% of the samples at ten different sampling sites. The median and 95th percentile values of all samples collected and analyzed in this survey were 3 and 152 ng/L respectively (n=125). The maximum concentration reported in the survey was 749 ng/L with mean and median values of 45 and 6 ng/L in detectable samples (n=63, "T" or greater). These values are lower than those that have been reported internationally where maximum concentrations have been reported up to 7,100 ng/L in source water in Germany (Weigel et al., 2004). In 2000, Metcalfe et al. conducted sampling study of surface waters in the Detroit River and Hamilton Harbour for carbamazepine. Maximum reported levels were 650 ng/L and 310 ng/L with median reported levels of 185 ng/L and 120ng/L respectively with percent detections ranging from 73 – 64% (Metcalfe et al., 2003). In a separate monitoring survey published in the same paper cited above, Metcalfe et al. conducted point surveys of Ontario source waters adjacent to discharges of effluents from sewage treatment plants. Sampling locations were: the Otonabee River, Hamilton Harbour, Little River and the Detroit River. Mean values reported were 2 ng/L, 23 ng/L, 80 ng/L and 4 ng/L respectively (Metcalfe et al., 2003). The percent detection and detected mean concentrations reported by Metcalfe are consistent with those reported in this survey. More recently, following the publication on the US National Reconnaissance of pharmaceuticals in untreated drinking waters, Focazio et al., 2008 reported a 21.6 percent detection, with a maximum concentration of 190 ng/L.

Gemfibrozil was detected in 33% of the samples at seven different sampling sites. The median and 95th percentile values of all samples collected and analyzed in this survey were 0.7 and 6 ng/L respectively (n=125). The maximum concentration reported in the survey was 9 ng/L with mean and median values of 3 and 1.9 ng/L in detectable samples (n=41, "T" or greater). These values are lower than those that have been reported internationally where maximum concentrations have been reported up to 710 ng/L in source water in the United States. In 2000, Metcalfe et al. conducted sampling of surface waters in the Detroit River and Hamilton Harbour for gemfibrozil. Maximum reported levels were 112 ng/L and 67 ng/L with median reported levels of 66 ng/L and 12ng/L respectively with percent detections ranging from 43 – 46% (Metcalfe et al., 2003). In a separate monitoring study published in the same paper cited above, Metcalfe et al. conducted point surveys of Ontario source waters adjacent to discharges of effluents from sewage treatment plants. Sampling locations were: the Otonabee River, Hamilton Harbour, Little River and the Detroit River. Mean values reported were non-detectable, 38 ng/L, 34 ng/L and 2 ng/L respectively (Metcalfe et al., 2003). The percent detection and detected mean concentrations reported by Metcalfe et al. are consistent with those reported in this survey although the maximum reported values are roughly ten times higher.

Bisphenol A (BPA) was detected in 22% of the samples at eleven different sampling sites. The median and 95th percentile values of all samples collected and analyzed in this survey were 2.1 and 44 ng/L respectively (n=125). The maximum concentration reported in the survey was 87 ng/L with mean and median values of 29 and 21 ng/L in detectable samples (n=27, "T" or greater). These values are much lower than those that have been reported internationally where maximum concentrations have been reported up to 12,000 ng/L in source water in the United States by Kolpin et al. (2002) (median 140 ng/L). Focazio et al., recently conducted a survey of pharmaceuticals and other organic wastewater contaminants in the United States. BPA was detected 9.5% of the time in untreated sources of drinking water in comparison to this study's detection of 22%. In 2003, Boyd et al., conducted several monitoring point surveys of North American raw drinking waters. BPA was detected in the Detroit River in that monitoring survey, but no values were reported. Willhite et al., in 2008 reported that an adult male weighing 70 kilograms could ingest 2 litres of water a day with BPA at a total allowable concentration (TAC) of 100 µg/L. This TAC value is approximately 1000 times higher than the maximum observed BPA concentration that was detected in one sample collected from this survey.

Ibuprofen was detected in 21% of the samples at nine different sampling sites. The median and 95th percentile values of all samples collected and analyzed in this survey were 0.98 and 24 ng/L respectively (n=125). The maximum concentration reported in the survey was 79 ng/L with mean and median values of 18 and 14 ng/L in detectable samples (n=26, "T" or greater). These values are lower than those that have been reported internationally where maximum

concentrations have been reported up to 2,700 ng/L in source water in Spain. In 2000, Metcalfe et al. conducted sampling of surface waters in the Detroit River and Hamilton Harbour for ibuprofen. Maximum reported levels were 790 ng/L and 93 ng/L with median reported levels of 141 ng/L and 64 ng/L respectively with percent detections ranging from 14 – 38% (Metcalfe et al., 2003). In a separate study published in the same paper cited above, Metcalfe et al. conducted point surveys of Ontario source waters adjacent to discharges of effluents from sewage treatment plants. Sampling locations were: the Otonabee River, Hamilton Harbour, Little River and the Detroit River. Mean values reported were non-detectable, 27 ng/L, 8 ng/L and non-detectable respectively (Metcalfe et al., 2003). The maximum values concentrations are higher than those reported in this study; however, the percent detection is comparable. More recently, Focazio et al., 2008 reported a 1.4 percent detection in source waters in the USA, with a maximum concentration of 270 ng/L.

Naproxen, similar to ibuprofen, naproxen was detected in 21% of the samples in untreated source water at 5 different sampling sites. The median and 95th percentile values of all samples collected and analyzed in this survey were 1.0 and 58 ng/L respectively (n=125). The maximum concentration reported in the survey was 199 ng/L with mean and median values of 40 ng/L and 21 ng/L in detectable samples (n=26, "T" or greater). In 2000, Metcalfe et al. conducted sampling of surface waters in the Detroit River and Hamilton Harbour for naproxen. Maximum reported levels were 551 ng/L and 139 ng/L with median reported levels of 207 ng/L and 94 ng/L respectively with percent detections ranging from 69 – 21% (Metcalfe et al., 2003). In a separate monitoring study published in the same paper cited above, Metcalfe et al. conducted point surveys of Ontario source waters adjacent to discharges of effluents from sewage treatment plants. Sampling locations were: the Otonabee River, Hamilton Harbour, Little River and the Detroit River. Mean values reported were non-detectable, 39 ng/L, 73 ng/L and non-detectable respectively (Metcalfe et al., 2003). In 2007, Servos et al. also reported a maximum concentration of 150 ng/L in river water downstream from a municipal wastewater plant located in Ontario. Overall, for naproxen, the range of values detected (mean, median, maximum) in Ontario are consistent across all the above reported studies.

Lincomycin was detected in 19% of the samples at six different sampling sites. The median and 95th percentile values of all samples collected and analyzed in this survey were 0.12 and 15 ng/L respectively (n=125).The maximum concentration reported in the survey was 143 ng/L with mean and median values of 14 ng/L and 5 ng/L in detectable samples (n=24, "T" or greater). Kolpin et al. (2002) reported lincomycin at a frequency of detection of 19% but had a higher median value of 60 ng/L and a maximum of 730 ng/L. The only other reports on the occurrence of lincomycin in Ontario is from work completed by Lissemore et al., (2006) on the pharmaceuticals detected within seven tributaries receiving primarily agricultural inputs in the Grand River watershed in Southern Ontario. It

was reported that lincomycin was the most frequently detected compound (n = 114 out of the 125 samples collected). The concentration ranged from 0.3 to 355 ng/L for samples collected from April to November 2003. More recently, lincomycin was not detected in any of the surface waters sampled in the USA by Focazio et al. (2008).

Sulfamethoxazole was detected in 18% of the samples at eight different sampling sites. The median and 95th percentile values of all samples collected and analyzed in this survey were 0.17 and 28 ng/L respectively (n=125). The maximum concentration reported in the survey was 284 ng/L with mean and median values of 34 ng/L and 14.3 ng/L in detectable samples (n=23, "T" or greater). Kolpin et al. (2002) reported sulfamethoxazole at a frequency of 19% with a median value of 66 ng/L and a maximum of 510 ng/L. More recently, Focazio et al., 2008 reported a 2.7 percent detection in source waters in the USA. There have been no previous reports of sulfamethoxazole in Ontario source waters.

Acetaminophen was detected in 11% of the samples at eight different sampling sites. The median and 95th percentile values of all samples collected and analyzed in this survey were 0.1 and 95 ng/L respectively (n=125). The maximum concentration reported in the survey was 298 ng/L with mean and median values of 109.7 ng/L and 60.1 ng/L in detectable samples (n=14, "T" or greater). These values are lower than the maximum value of 10,000 ng/L reported by Kolpin et al. (2002) in source water in the United States, but are fairly consistent with Focazio et al. (2008) who reported 8.7 percent detection in source waters with a maximum concentration of 160 ng/L.

Benzafibrate was detected in 10% of the samples at two different sampling sites. The median and 95th percentile values of all samples collected and analyzed in this survey were 0.2 and 2 ng/L respectively (n=125). The maximum concentration reported in the survey was 3.6 ng/L with both mean and median values of 1.9 ng/L in detectable samples (n=13,"T" or greater). These values are lower than those that have been reported internationally where maximum concentrations have been reported up to 3,100 ng/L in source water in Germany (Ternes et al., 1998). In 2000, Metcalfe et al. conducted sampling of surface waters in the Detroit River and Hamilton Harbour for benzafibrate. The maximum reported level was 200 ng/L with a median level of 52 ng/L in the Detroit River (Metcalfe et al., 2003). In a separate monitoring study published in the same paper cited above, Metcalfe et al. conducted point surveys of Ontario source waters adjacent to discharges of effluents from sewage treatment plants. Sampling locations were: the Otonabee River, Hamilton Harbour, Little River and the Detroit River. Mean values reported were non-detect, 10 ng/L, 137 ng/L and non-detect respectively (Metcalfe et al., 2003). These values are generally higher than the reported detected mean and median values in this study.

Trimethoprim was detected in 10% of the samples at three different sampling sites. The median and 95th percentile values of all samples collected and analyzed in this survey were 0.4 and 11 ng/L respectively (n=130). The maximum concentration reported in the survey was 25 ng/L with mean and median values of 10.6 ng/L and 9.6 ng/L in detectable samples (n=13, "T" or greater). These values are lower than those that have been reported internationally where maximum concentrations have been reported up to 710 ng/L in source water in the United States (Kolpin et al., 2002). Metcalfe et al. (2003) conducted several monitoring point surveys of Ontario source waters adjacent to discharges of effluents from sewage treatment plants. Sampling locations were: the Otonabee River, Hamilton Harbour, Little River and the Detroit River. Mean values reported were non-detect, 43 ng/L, 134 ng/L and non-detect respectively. More recently, Focazio et al., (2008) reported an 8.1 percent detection in source waters in the USA, with a maximum concentration of 160 ng/L. These results are generally consistent with what we have reported in our survey.

Sulfamethazine was detected in 10% of the samples at four different sampling sites. The median and 95th percentile values of all samples collected and analyzed in this survey were 0.055 and 4.5 ng/L respectively (n=125). The maximum concentration reported in the survey was 34 ng/L with mean and median values of 9.2 ng/L and 6.9 ng/L in detectable samples (n=12, "T" or greater). These values and percent detection are higher than those that have been previously reported. In 2002, Kolpin et al. reported 1/84 samples with sulfamethazine at a concentration of 220 ng/L. Although this value is higher than that observed in this survey, we found a higher percent detection in Ontario source waters. More recently, Focazio et al., (2008) reported that sulfamethazine was not detected in any source water samples taken in the United States.

4.2.3 Levels, Occurrence and Description of the Most Frequently Detected Compounds in Finished Drinking Water

This section provides a detailed description of the concentrations (median, 95th percentile and maximum values) of the most frequently detected compounds (≥ 10%, Table 7) in finished drinking water and how these levels compare to previous reports and other jurisdictions.

Table 7: Number of Detections and Concentrations for Most Frequently Detected Compounds in Finished Drinking Water (from river and lake sources) in Ontario (n= 123)

Compound	Number of Detections	Detection Percentage (%)	Detection Limit (ng/L)	Median (ng/L)	95th Percentile (ng/L)	Maximum (ng/L)
Carbamazepine	31	25%	1	0.21	37	601
Ibuprofen	19	15%	0.5	0.33	12	25
Gemfibrozil	18	15%	1	0.5	2	4
BPA	15	12%	2	0.14	17	99

Carbamazepine was detected in 25% of the samples at eight different sampling sites. The median and 95th percentile values of all samples collected and analyzed in this survey were 0.21 and 37 ng/L respectively (n=123). The maximum concentration reported in the survey was 601 ng/L with mean and median values of 40 ng/L and 6 ng/L in detected samples (n=31, "T" or greater). In 2003, CTV conducted a quantitative analysis of pharmaceuticals in drinking water from Ten Canadian Cities (Tauber et al., 2003). Carbamazepine was detected in single samples collected from Brooks, Alberta (24 ng/L), Hamilton, Ontario (6.5 ng/L) and Montreal, Quebec (8.4 ng/L). In 2004, Stacklberg et al., reported a maximum concentration of 258 ng/L carbamazepine in finished drinking water in the United States. Most recently, Hua et al. (2006) reported levels of carbamazepine in finished drinking water collected in Windsor, Ontario with a mean value of 2 ng/L or below for water not treated with ozone and non-detectable levels for water treated with ozone.

Ibuprofen was detected in 15% of the samples in finished drinking water samples at nine different sampling sites. The median and 95th percentile values of all samples collected and analyzed in this survey were 0.33 and 12 ng/ respectively (n=123). The maximum concentration reported in the survey was 25 ng/L with mean and median values of 10 ng/L and 8.5 ng/L in detected samples (n=19, "T" or greater). These values are lower than those that have been reported internationally, where maximum concentrations have been reported at 1,350 ng/L, a mean concentration 930 ng/L and a percent detection of around 13 percent in finished drinking water in the United States (Loraine and Pettigrove, 2006). Ibuprofen was not detected in any samples in the 2003 CTV survey of pharmaceuticals in drinking water. A recent survey conducted by the National Water Research Institute (Servos et al., 2007) of 20 drinking water plants in Ontario detected ibuprofen at levels as high as 112 ng/L (average 4.8 ng/L). A research group lead by Schwab et al. (2005) published calculated Predicted No Effect Concentrations (PNECs) for children for a suite of pharmaceuticals in drinking water. The PNEC for ibuprofen was 1,600,000 ng/L. This value is

approximately 5 orders of magnitude higher than the maximum concentration reported in this survey.

Gemfibrozil was detected in 15% of the samples at six different sampling sites at trace levels. The median and 95th percentile values of all samples collected and analyzed in this survey were 0.5 and 2 ng/L respectively (n=123).The maximum concentration reported in the survey was 4 ng/L with mean and median values of 2 ng/L and 1.8 ng/L in detected samples (n=18, "T" or greater). These values are much lower than those that have been previously reported. For example, in 2004, Jones et al. reported a maximum concentration of 70 ng/L in Canadian drinking water as reported in the 2003 survey conducted by CTV's report on the "Quantitative Analysis of Pharmaceuticals in drinking water from Ten Canadian Cities". Gemfibrozil was only detected in one sample at a concentration of 70 ng/L collected from Portage La Prairie, Manitoba. A research group lead by Schwab et al. (2005) published calculated Predicted No Effect Concentrations (PNECs) for children for a suite of pharmaceuticals in drinking water. The PNEC for gemfibrozil was 800,000 ng/L. This value is approximately 5 orders of magnitude higher than the maximum concentration reported in this survey.

BPA was detected in 12% of the samples in finished drinking water samples at eleven different sampling sites. The median and 95th percentile values of all samples collected and analyzed in this survey were 0.14 and 17 ng/L respectively (n=123). The maximum concentration reported in the survey was 99 ng/L with mean and median values of 23 ng/L and 14 ng/L in detected samples (n=15, "T" or greater). These values are lower than those that have been reported internationally where a maximum concentration of 420 ng/L was reported in the United States (Loraine and Pettigrove, 2006). A recent publication estimated a total allowable concentration for an adult human (70kg), who ingests 2 litres of drinking water per day, to be 100 µg/L (Whillhite et al., 2008). This value is 1000 times higher (3 orders of magnitude) than the maximum concentration that was detected in one sample collected from this survey.

4.3 Effectiveness of Treatment Systems

In reviewing treatment systems and reduction efficiencies, the levels of pharmaceuticals and other emerging contaminants were not expected to change within the retention time of a drinking water system. Therefore, retention times were not considered in comparing source water to drinking water samples. Furthermore, data were limited for samples collected from facilities with different treatment processes and did not include metabolites or degradation products.

For the most frequently detected compounds, concentrations in finished drinking water were generally lower than the concentrations in untreated source water, based on a comparison of distributions of the pooled data for the source water (river and lake sources) and drinking water. This suggests that, generally speaking, existing drinking water treatment can reduce these parent compounds (Figures 2-5)[3]. For the remaining compounds that were detected in source water but not in drinking water (sulfamethoxazole, acetaminophen, benzafibrate and trimethoprim), the reduced frequency of detection may also be indicative of reduction through drinking water treatment (i.e., ≥ 10% detection in source water versus ≤ 2% in drinking water) (Tables 6 and 7).

[3] For each compound, the lognormal distribution of all the data from the source water and the drinking water was plotted for a visual comparison (Figures 2-5). The lognormal distribution plots were generated using censored regression on order statistics (ROS) of the complete log transformed datasets using Minitab routines (Helsel, 2009) which generally provided a good fit for the results observed.

Figure 2: Log normal distribution of the concentration of carbamazepine in untreated source (detect=64, non-detect=61) and finished drinking waters (detect=31, non-detect=92) from different water treatment plants. The MDL was 1 ng/L.

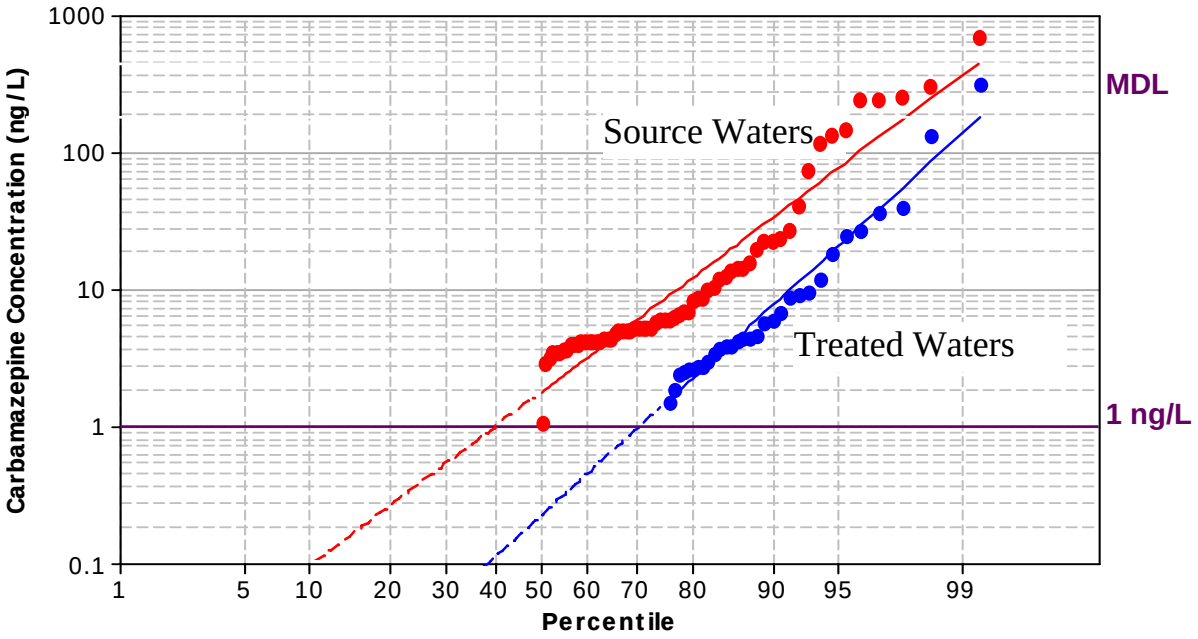


Figure 3: Log normal distribution of the concentration of bisphenol A in untreated source (detect=27, non-detect=98) and finished drinking waters (detect=15, non-detect=115) from different water treatment plants. The MDL was 2 ng/L.

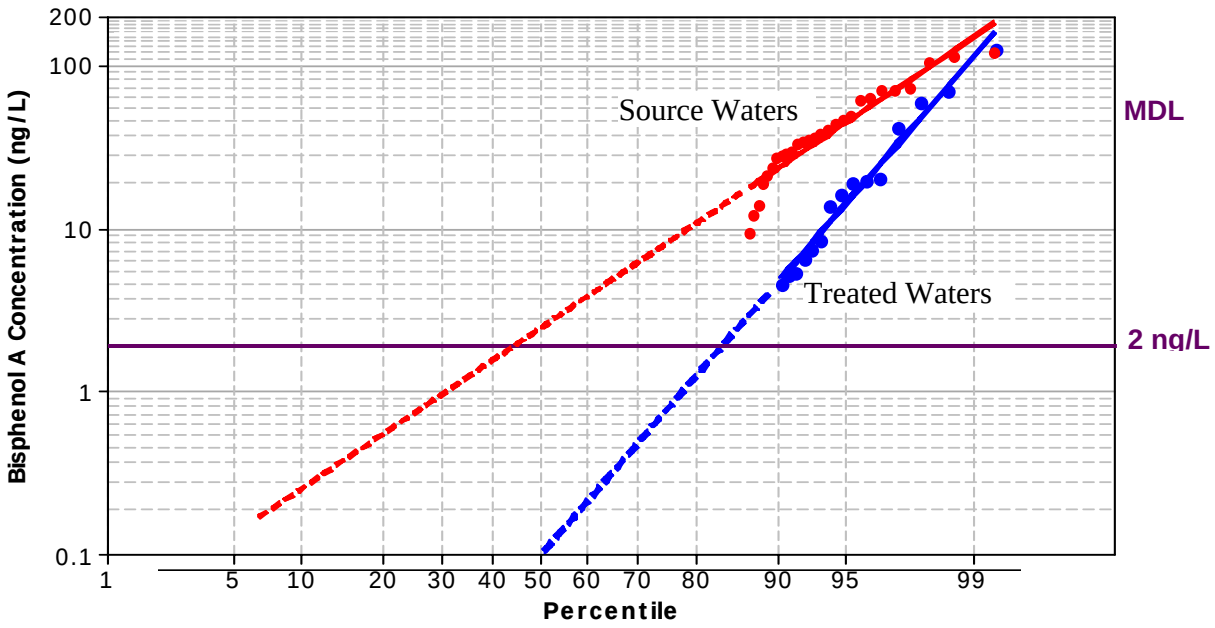


Figure 4: Log normal distribution of the concentration of ibuprofen in untreated source (detect=25, non-detect=100) and finished drinking waters (detect=18, non-detect=105) from different water treatment plants. The MDL was 0.5 ng/L.

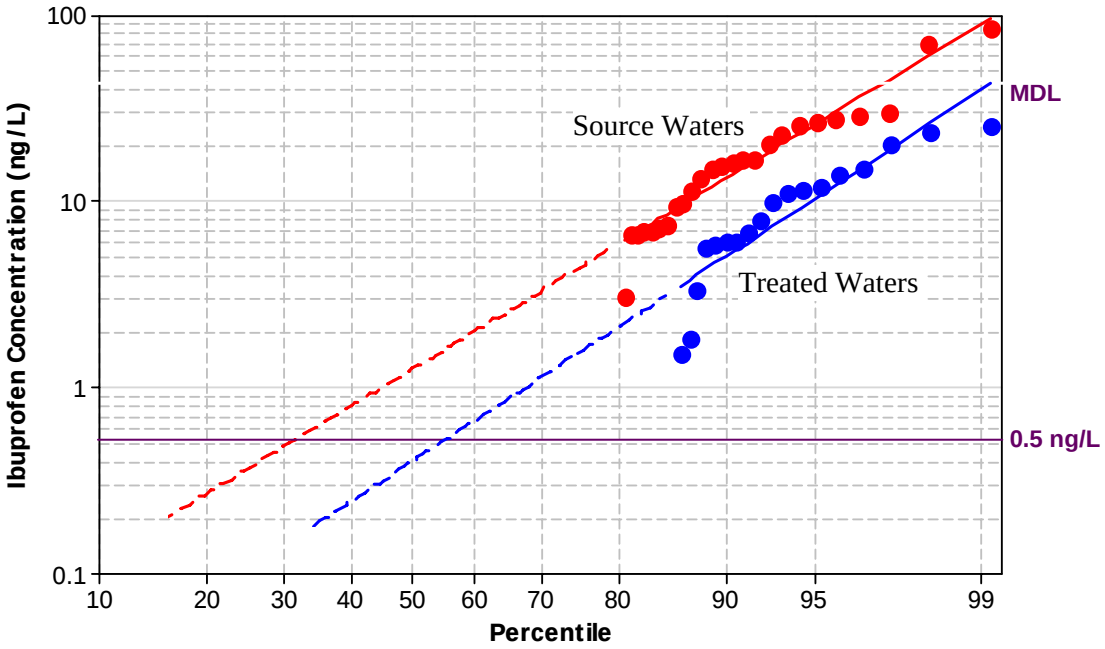
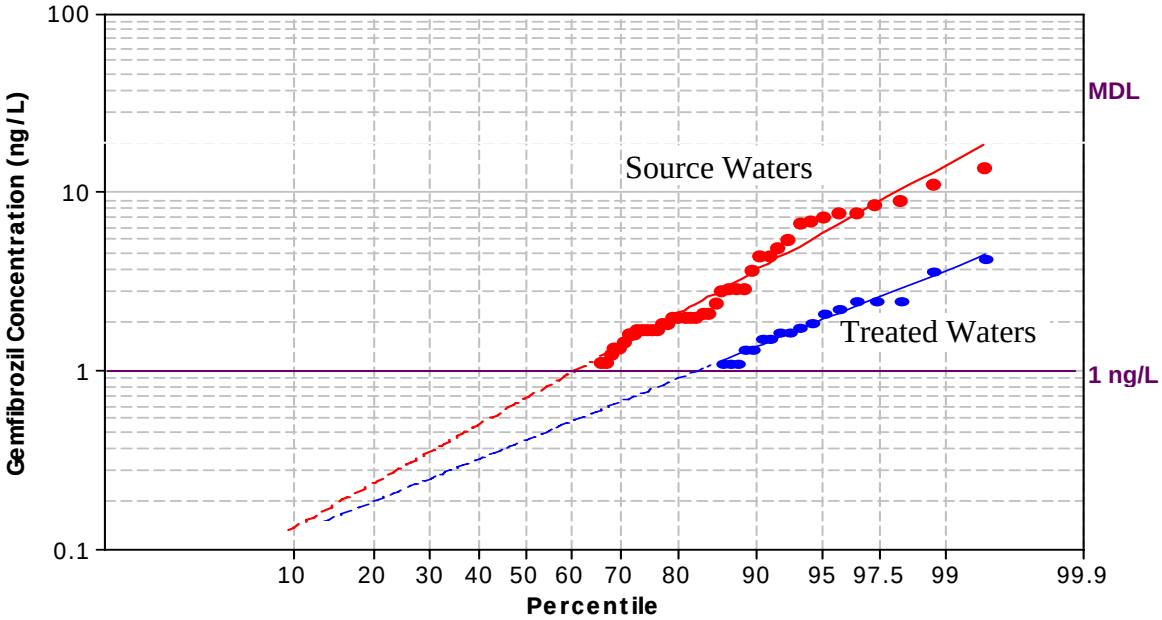


Figure 5: Log normal distribution of the concentration of gemfibrozil in untreated sources waters (detect=41, non-detect=84) and treated waters (detect=18, non-detect=105) from different water treatment plants. The MDL was 1 ng/L.



5.0 Conclusions

This survey confirms that certain pharmaceuticals and BPA are detected at trace levels in Ontario's untreated source water and finished drinking water. The detection and concentrations of the most frequently detected compounds in untreated source and finished drinking waters (carbamazepine, gemfibrozil, ibuprofen and bisphenol A), were generally consistent with those of previous studies in Canada and Ontario and generally lower than those of international studies.

The fact that a compound can be detected in drinking water does not mean that there is a direct risk to human health. The levels detected were well below any therapeutic level or estimated maximum acceptable daily intake (ADI) for drinking water. To put the results into perspective, an individual would have to drink thousands of glasses of drinking water a day to reach a maximum acceptable daily intake (ADI) for any of the most frequently detected compounds in the finished drinking water. The ministry will continue to support research, monitoring and trend analysis of pharmaceuticals and other chemicals of emerging concern in Ontario's source and drinking waters.

Comparisons of the distributions of source water concentrations to those of finished drinking water indicate that the most frequently detected parent compounds are reduced after moving through a drinking water treatment system. However, it is unclear which treatments are most effective and whether compounds are destroyed or transformed to degradation products. Further work would be warranted to better understand the effectiveness of individual treatment technologies in reducing parent compounds as well as their metabolites or degradation products.

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APPENDIX A

Chemicals Analyzed in Untreated Source Water and Drinking Water with Quality Assurance and Quality Control Data

Compound Name	CAS #	Formula	IDL ng/L	MDL ng/L	Avg. % R	RSD	% RRD	N
Pharmaceuticals								
Acetaminophen *	103-90-2	$C_8H_9NO_2$	0.5	2.0	103%	12%	8%	64
Benzafibrate	41859-67-0	$C_{19}H_{20}ClNO_4$	0.01	0.5	89%	21%	7%	64
Carbamazepine *	298-46-4	$C_{15}H_{12}N_2O$	0.004	1.0	96%	6%	8%	64
Clofibric acid *	882-09-7	$C_{10}H_{11}ClO_3$	0.6	1.0	99%	20%	10%	64
Diclofenac *	15307-86-5	$C_{14}H_{11}Cl_2NO_2$	0.03	1.0	106%	15%	9%	64
Gemfibrozil *	25812-30-0	$C_{15}H_{22}O_3$	0.06	1.0	108%	8%	7%	64
Ketoprofen	22071-15-4	$C_{16}H_{14}O_3$	0.06	2.0	124%	19%	9%	64
Ibuprofen *	15687-27-1	$C_{13}H_{18}O_2$	1.2	0.5	102%	10%	8%	64
Indomethacin *	53-86-1	$C_{19}H_{16}ClNO_4$	1.2	5.0	100%	10%	31%	64
Naproxen *	22204-53-1	$C_{14}H_{14}O_3$	0.15	2.0	100%	5%	10%	64
Warfarin	81-81-2	$C_{19}H_{16}O_4$	0.02	5.0	96%	13%	7%	64
Antibiotics, B-Lactam								
Penicillin G	61-33-6	$C_{16}H_{18}N_2O_4S$	2	2.0	83%	70%	40%	64
Antibiotics, Fluoroquinolones								
Ciprofloxacin *	85721-33-1	$C_{17}H_{18}FN_3O_3$	0.3	0.5	101%	8%	11%	64
Enrofloxacin	93106-60-6	$C_{19}H_{22}FN_3O_3$	0.01	5.0	407%	45%	11%	20
Norfloxacin	70458-96-7	$C_{16}H_{18}FN_3O_3$	0.01	10.0	644%	59%	15%	20
Antibiotics, Tetracyclines								
Chlorotetracycline	57-62-5	$C_{22}H_{23}ClN_2O_8$	0.5	10.0	57%	80%	25%	64
Doxycycline	564-25-0	$C_{22}H_{24}N_2O_8$	1.5	5.0	182%	35%	10%	64
Meclocycline	2013-58-3	$C_{22}H_{21}ClN_2O_8$	2.5	5.0	266%	36%	11%	64
Oxytetracline	79-57-2	$C_{22}H_{24}N_2O_9$	0.07	5.0	163%	31%	10%	64
Tetracycline	60-54-8	$C_{22}H_{24}N_2O_8$	0.2	10.0	173%	32%	10%	64
Antibiotics, Macrolide								

Compound Name	CAS #	Formula	IDL ng/L	MDL ng/L	Avg. % R	RSD	% RRD	N
Erythromycin	114-07-8	$C_{37}H_{67}NO_{13}$	0.01	10.0	137%	46%	14%	64
Lincomycin	154-21-2	$C_{18}H_{34}N_2O_6S$	0.01	0.5	113%	21%	10%	64
Virginiamycin M1	21411-53-0	$C_{28}H_{35}N_3O_7$	0.2	5.0	47%	49%	32%	64
Roxithromycin	80214-83-1	$C_{41}H_{76}N_2O_{15}$	0.02	2.0	148%	64%	19%	64
Antibiotics, Sulfonamides								
Sulfachloropyridazine	80-32-0	$C_{10}H_9ClN_4O_2S$	0.03	5.0	123%	21%	10%	64
Sulfamerazine	127-79-7	$C_{11}H_{12}N_4O_2S$	0.01	1.0	91%	31%	10%	64
Sulfadiazine	68-35-9	$C_{10}H_{10}N_4O_2S$	0.2	5.0	91%	15%	11%	64
Sulfamethizole	144-82-1	$C_9H_{10}N_4O_2S_2$	0.03	2.0	117%	21%	13%	64
Sulfamethoxazole *	723-46-6	$C_{10}H_{11}N_3O_3S$	0.03	2.0	100%	5.3%	10%	64
Sulfathiazole	72-14-0	$C_9H_9N_3O_2S_2$	0.03	2.0	90%	25%	11%	64
Antibiotics, Veterinary								
Carbadox	6804/07/05	$C_{11}H_{10}N_4O_4$	0.6	10.0	70%	19%	9%	64
Lasaloid A	25999-31-9	$C_{34}H_{53}O_8Na$	0.04	10.0	122%	36%	11%	64
Sulfadimethoxine	122-11-2	$C_{12}H_{14}N_4O_4S$	0.01	1.0	105%	26%	9%	64
Sulfamethazine *	57-68-1	$C_{12}H_{14}N_4O_2S$	0.03	1.0	101%	6%	5%	64
Tylosin	1401-69-0	$C_{46}H_{77}NO_{17}$	0.2	10.0	177%	46%	13%	64
Chloramphenicol	56-75-7	$C_{11}H_{12}Cl_2N_2O_5$	0.03	2.0	91%	16%	5%	64
Trimethoprim	738-70-5	$C_{14}H_{18}N_4O_3$	0.01	1.0	100%	25%	13%	64
Monensin sodium	22373-78-0	$C_{36}H_{61}NaO_{11}$	0.03	10.0	190%	49%	15%	64
Hormones								
17-α-Estradiol	57-91-0	$C_{18}H_{24}O_2$	0.3	5.0	113%	15%	9%	64
17-α-Ethynyl Estradiol	57-63-6	$C_{20}H_{24}O_2$	0.6	5.0	104%	17%	12%	64
17-β-Estradiol	50-28-2	$C_{18}H_{24}O_2$	1	2.0	112%	14%	11%	64
Norethisterone	68-22-4	$C_{20}H_{26}O_2$	5.1	5.0	99%	17%	11%	64
Diethylstilbestrol	56-53-1	$C_{18}H_{20}O_2$	0.5	10.0	143%	30%	13%	64

Compound Name	CAS #	Formula	IDL ng/L	MDL ng/L	Avg. % R	RSD	% RRD	N
*Equilin**	474-86-2	$C_{18}H_{20}O_2$	0.2	2.0	105%	13%	10%	64
*Estrone**	53-16-7	$C_{18}H_{22}O_2$	0.3	2.0	113%	13%	8%	64
Estriol	50-27-1	$C_{18}H_{24}O_3$	0.1	5.0	86%	24%	17%	64
Progesterone *	57-83-0	$C_{21}H_{30}O_2$	3.4	20.0	87%	11%	19%	64
Emerging Contaminants								
*Bisphenol A**	80-05-7	$C_{15}H_{16}O_2$	0.3	2.0	106%	11%	8%	64
Radioisotope Labeled Standards								
$^{2}H_{10}$-Carbamazepine	--	Surrogate	--	--	--	--	--	--
$^{13}C_3{}^{15}N$-Ciprofloxacin	--	Surrogate	--	--	--	--	--	--
$^{2}H_3$-Ibuprofen	--	Surrogate	--	--	--	--	--	--
$^{13}C^{2}H_3$-Naproxen	--	Surrogate	--	--	--	--	--	--
$^{2}H_9$-Progesterone	--	Surrogate	--	--	--	--	--	--
$^{13}C_6$-Sulfamethoxazole	--	Surrogate	--	--	--	--	--	--
$^{13}C_6$-Sulfamethazine	--	Surrogate	--	--	--	--	--	--
$^{2}H_4$-Acetaminophen	--	Surrogate	--	--	--	--	--	--
$^{2}H_4$-Clofibric acid	--	Surrogate	--	--	--	--	--	--
$^{2}H_4$-Diclofenac	--	Surrogate	--	--	--	--	--	--
$^{2}H_6$-Gemfibrozil	--	Surrogate	--	--	--	--	--	--
$^{2}H_4$- Indomethacin	--	Surrogate	--	--	--	--	--	--
$^{2}H_4$-Equilin	--	Surrogate	--	--	--	--	--	--
$^{2}H_4$-Estrone	--	Surrogate	--	--	--	--	--	--
$^{2}H_{16}$-Bisphenol A	--	Surrogate	--	--	--	--	--	--

* Compounds analyzed with radioisotope standard.
CAS #: Chemical Abstract Service number
IDL: Instrument Detection Limit
MDL: Method Detection Limit
Avg. %R: Average percent recovery
RSD: Relative Standard Deviation
%RRD: Relative Difference in the Recovery (% RRD) where
%RRD = 100*absolute value (R1-R2) / (0.5*(R1+R2)
R1 = spike sample 1 and R2 = spiked sample 2.
N: number samples analyzed for QA/QC data

APPENDIX B

Detected and Non Detected Compounds in the Survey

Compounds detected in the survey in untreated source or finished drinking water	Compounds not detected in the survey
ACETAMINOPHEN	17-ALPHA-ESTRADIOL
BENZAFIBRATE	17-ALPHA-ETHYNYL ESTRADIOL
BISPHENOL A	17-BETA-ESTRADIOL
CARBAMAZEPINE	CARBADOX
CLOFIBRIC ACID	CHLORAMPHENICOL
DICLOFENAC	CHLOROTETRACYCLINE
ENROFLOXACIN	CIPROFLOXACIN
EQUILIN	DIETHYLSTILBESTEROL
ERYTHROMYCIN	DOXYCYCLINE
GEMFIBROZIL	ESTRIOL
IBUPROFEN	ESTRONE
KETOPROFEN	INDOMETHACIN
LINCOMYCIN	LASALOID A
MECLOCYCLINE	PROGESTERONE
MONENSIN SODIUM	SULFADIAZINE
NAPROXEN	SULFADIMETHOXINE
NORETHISTERONE	SULFAMERAZINE
NORFLOXACIN	SULFAMETHIZOLE
OXYTETRACLINE	WARFARIN
ROXITHROMYCIN	
SULFACHLOROPYRIDAZINE	
SULFAMETHAZINE	
SULFAMETHOXAZOLE	
SULFATHIAZOLE	
TETRACYCLINE	
TRIMETHOPRIM	
TYLOSIN	